Feeding the Future

Innovation Requirements for Primary Food Production in the UK to 2030




Prepared by the Joint Commissioning Group[1]

(Principal Editor Chris Pollock, Aberystwyth University)

1 Full details of the membership of the Joint Commissioning Group can be found in Appendix 1

AHDB Agriculture & Horticulture Development Board

aic agricultural industries confederation

Royal Agricultural Society of England

NFU

NFU Scotland

www.feedingthefuture.info

Contents

Foreword

Jim Godfrey OBE, farmer and member of the Joint Commissioning Group

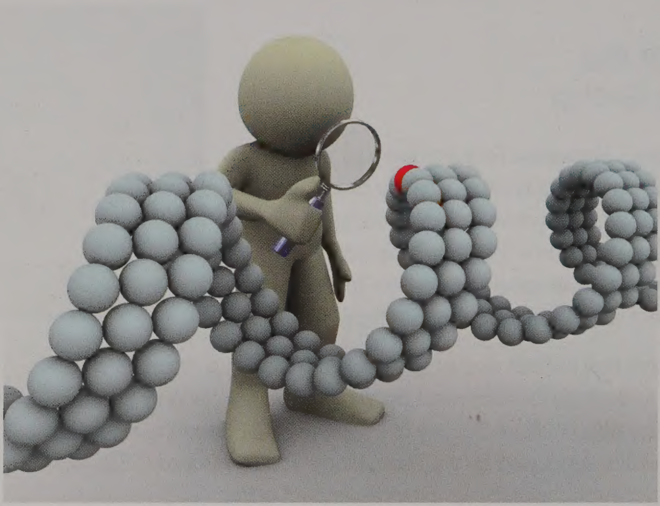
This document – *Feeding the Future – Innovation Requirements for Primary Food Production in the UK to 2030* – is the result of UK primary producers coming together to identify their research and development priorities for the next 20 years: it is the first time in my lifetime that they have done so. It is timely, because the Government is developing its own Agri-Technology Strategy, and is using this document to help develop that Strategy.

The Joint Commissioning Group that has put this document together includes a representative from each of the Agriculture and Horticulture Development Board (AHDB), the National Farmers' Union (NFU), NFU Scotland, the Royal Agricultural Society of England (RASE) and the Agricultural Industries Confederation (AIC), and it is supported by the Technology Strategy Board (TSB), with Professor Chris Pollock from Aberystwyth University as the independent editor.

The resulting report has built upon existing R&D priorities from the different sectors, both within and outside of the AHDB. As part of the evidence-gathering process, the group organised a number of workshops, and has consulted widely to produce a document which articulates farmers' and growers' views of their priorities for research over the next two decades. It has identified gaps in current research, and also looked at research and innovation in agriculture and horticulture as a whole system. It is a document that we will take to the funders of research and development, which include the Biotechnology and Biological Sciences Research Council (BBSRC), the Department for the Environment, Food and Rural Affairs (Defra), the Scottish, Welsh and Northern Irish devolved administrations, the Department for International Development (DfID), the TSB, the AHDB and the private sector. Our aim is to influence their funding priorities, so that we as a nation can better co-ordinate our strategic planning and use of the resources that are available to us, to improve the productivity, competitiveness and sustainability of UK agriculture and horticulture.

UK farmers and growers have a good record of innovation, and will work closely with research partners on agreed priorities, to deliver what is required. This document is the start of that process: we must ensure that we act on it, though it will require updating as we see changes in the challenges of feeding the UK and world populations, and in the technologies that are available to help us do so.

Summary of Research Priorities and Recommendations



With the objective of identifying generic R&D priorities, an independent group of industry organisations (the Joint Commissioning Group) has organised a series of workshops and parallel consultations with key industry stakeholders. If the following priorities are addressed in a timely manner and with sufficient vigour, we anticipate positive outcomes for the UK industry, helping it to respond to the challenges and opportunities associated with increased volatility in global markets, both for inputs and products.

Although the remit of the Joint Commissioning Group related only to R&D relevant to food production, the issues it has identified are also relevant to the development of other products of the land. These generic issues are grouped under seven themes, based upon the findings of the workshops. The findings summarised below should be viewed as a suite of proposals that could form the basis for future concerted actions by a range of funders.

Research Priorities

1 Use of modern technologies to improve the precision and efficiency of key agricultural management practices.

- Develop remote monitoring, control and application technologies to optimise input use efficiency, improve animal health and welfare, sustain product quality and safety, reduce the impact of machinery traffic on land, and promote effective delivery of environmental goods and services
- Integrate and use the increasing volume of yield mapping and recording, and soil, crop and animal data, in order to develop better decision-support tools for integrated farming systems

- Improve machine and instrument flexibility, inter-operability and applicability to the UK environment, in order to promote delivery of the above
- Develop integrated strategic approaches to the use of nutrients and substrates to reduce environmental impact
- Develop strategies for building/ store design that improve crop quality, animal health and welfare, and productivity
- Develop improved and integrated pre- and post-farm-gate handling and storage solutions for perishable crops, which ensure that added value is retained and protected.

2 Apply modern genetic and breeding approaches to improve the quality, sustainability, resilience and yield-led profitability of crops and farm animals.

- Develop practical approaches for managing, curating, disseminating and using 'omics' information and related large data sets for effective precision breeding of plants and animals
- Use better understanding of plant architecture, development and biochemistry to identify breeding targets for improved resource use efficiency and tolerance of biotic and abiotic stress in crops, now and under future climate conditions
- Generate more effective genetic improvement strategies for the ruminant sector, which identify and manipulate relevant traits and their genetic drivers, rather than emphasising specific breed improvement.

3 Use systems-based approaches to better understand and manage interactions between soil, water and crop/ animal processes.

- Improve understanding of rhizosphere processes and the interactions between flows of carbon, water and nutrients under different management conditions
- Improve knowledge and management of soil health in arable, horticultural, pastoral and mixed systems, and link this to better water and waste management
- Improve support tools for the management of agricultural systems that optimise nutrient use and potential productivity, whilst mitigating the associated greenhouse gas (GHG) emissions, other forms of diffuse pollution and losses
- Develop strategies to meet the production and utilisation requirements for plant and animal protein from within UK farming systems.

4 Develop integrated approaches to the effective management of crop weeds, pests and diseases within farming systems.

- Develop strategies (including novel rotations) that are compatible with continuing restrictions on the availability of approved chemical controls for crop pests, diseases and weeds
- Continue to translate improved understanding of the genetic basis of disease resistance into breeding targets for crop plants that offer durable and sustainable control options.

5 Develop integrated approaches to the management of animal disease within farming systems.

- Promote the development of effective vaccines and control strategies for endemic and emerging animal diseases, including through understanding of the genetic basis of resistance, and translating this into breeding targets
- Improve the linkage between welfare-oriented management and the use of precision breeding approaches to reduce the incidence of stress-related, non-pathogenic disorders in livestock, and any subsequent human infection disease risk.

6 Develop evidence-based approaches to valuing ecosystem service delivery by land users, and incorporate these approaches into effective decision-support systems at the enterprise or grouped enterprise level.

- Develop new models for integrated mixed farming, based around co-location of specialist enterprises, optimising value from crop diversification and co-products, and thereby generating a safe and sustainable 'circular agricultural economy'
- Promote development of the knowledge base, to provide understanding of the mechanisms by which ecological networks deliver ecosystem value through inter- and intra-species diversity

- Develop (in concert with other countries in the EU and elsewhere) robust tools for measuring, valuing and monitoring ecosystem service outputs from a range of farming systems. Incorporate these into advanced management strategies and effective decision-support tools
- Encourage investigation of the wider plant genetic resource base and its role in the mitigation of GHG emissions and diffuse pollution
- Develop regional models to assist policy-makers to manage the relationship between the delivery of essential ecosystem services and changes in the patterns of land ownership, tenure and use.

7 Extend the training, professional development and communication channels of researchers, practitioners and advisors to promote delivery of the targets above.

- Work with Higher Education Institutions (HEIs), the UK Research Councils (RCUK), the Department for Business, Innovation and Skills (BIS) and the wider agribusiness/ advisory sector to identify key research/ technical skills that are in short supply or absent in the UK. Develop approaches to improve the supply of graduates and postgraduates with relevant training both as researchers and as technical support specialists for agribusiness
- Work with HEIs, Further Education Institutions (FEIs) and others to develop continuing professional development (CPD) across agribusiness that will integrate with and support existing extension activities
- Develop structures to facilitate the greater use of practical 'demonstration' techniques as part of a wider training scenario
- Develop strategies to ensure effective knowledge exchange between researchers and advisors, to improve understanding and maximise development and innovation opportunities.

8 Improve the use of social and economic science to promote the development, uptake and use of sustainable, resilient and profitable agricultural practice that can deliver affordable, safe and high-quality products.

- Develop a series of 'good practice' case studies for effective knowledge exchange between researchers, advisors and farmers
- Evaluate common features so that future research can be commissioned that maximises the likelihood of effective delivery
- Investigate further options to identify 'best practice' from wider dissemination of research carried out by the agricultural supply industry, without compromising company profitability
- Identify the potential economic and social constraints on farmers that might slow or prevent uptake of new knowledge, including the effects of public opinion, and how these constraints might alter over time
- Carry out socio-economic evaluations of the costs of new technology and the ways that it might be introduced.

Recommendations

In order to promote this programme of long-term strategic and applied research, the Joint Commissioning Group presents five specific recommendations for the attention of public and private research funders and providers.

A. Levy bodies and other producer groups should consider ways in which they could help to establish joint programmes, based on the recommendations above, and leverage additional investment from the Research Councils, Government Departments, the TSB, the EU and other funding agencies.

B. Research Councils, Government Departments and, where appropriate, HEIs and Research Institutes should seek broader representation from producers on relevant councils, boards and committees. Levy bodies and other producer groups should nominate representatives who will work to foster long-term, integrated approaches to the challenges outlined in this document, rather than promoting narrow sectoral interests.

C. Given the increasing policy emphasis on land-based issues, including food production, alternative land use, climate change adaptation and mitigation, and the protection of natural capital, there needs to be an integrated consideration of options to improve the provision of advice, training and skilled manpower at a UK level, both in terms of producers and of the skills available within the R&D and consultancy base.

D. The policy and strategy implications associated with the research recommendations in this report should be considered holistically both by the Government and the funders of basic and strategic research. In governmental terms, there is a need to ensure that there is consistency of policy and approach between different Departments with an interest in land and water use, food and energy production, and the protection of natural capital.

E. In terms of the funders of research, thought needs to be given to how future strategic decisions over 'blue-sky' and responsive-mode funding can be managed, to protect the UK capacity for scientific excellence whilst addressing skills shortages in key areas, such as soil science and applied crop sciences. A more appropriate balance between fundamental and applied research, and closer interaction between science, advisory and farmer communities must be encouraged.

Next Steps

1. Representatives of the producer funding organisations should consider Recommendation A, and seek agreement on ways of consolidating the funding of longer-term generic research.
2. Following this, discussions should take place with other relevant funders (the Research Councils, Government Departments, the TSB etc) to agree a priority order and timelines for addressing the research priorities, and to establish procedures to specify, commission, monitor and disseminate outputs.
3. Simultaneously with 1, representatives of the producer funding organisations should contact the Biotechnology and Biological Sciences Research Council (BBSRC), the Natural Environment Research Council (NERC) and other relevant organisations, with proposals to increase producer representation.
4. A BIS/ Defra Agri-Tech Strategy is due to be published in the summer of 2013. This offers an excellent opportunity for producers to take a lead in responding to the Government's stated future direction for the industry. The AHDB, the AIC and other organisations representing industry interests should engage actively with the Government in devising optimum ways of delivering in shared priority areas.
5. In terms of promoting a consistent approach within the Government to sustaining production agriculture as an essential foundation of the UK food and drink industry, and achieving sustainable intensification, the Joint Commissioning Group should work with other interested parties to develop common positions on research and knowledge exchange.
6. The Joint Commissioning Group should discuss with the BBSRC the implications of recommendation E. The Group should also identify any priority areas where skills shortages are currently constraining progress.

Feeding the Future

Innovation Requirements for Primary Food Production in the UK to 2030

I. Introduction

Rationale

Ever since Malthus, concerns has been expressed regarding the capacity of agriculture to feed an ever-increasing population. To date, these concerns have been groundless; the area of land devoted to pastures and under cultivation for crops has increased and, particularly over the last century, yields of crops and livestock products have increased through the application of science and technology.

There are those who feel that this process can continue, and that the global food system is potentially resilient enough to cope with future demands, providing that underlying issues of equity and social value are addressed (IAASTD 2008[2]). However, an increasing number of international groupings of academics, politicians and producers feel that the first half of the 21st century will bring challenges that cannot be addressed by the continuation of existing approaches to increasing food production.

In other words, 'business as usual' is not an option. These challenges have been summarised by the then Government Chief Scientific Adviser, Professor Sir John Beddington[3], who talks about a 'perfect storm' of inter-related and additive factors, summarised in Table 1.

Table 1. Factors likely to constrain the ability of the global food chain to meet demands by mid-century (Royal Society, 2009)

1	Increase of population to 9bn, needing yield increases of up to 50% to maintain current levels of nutrition.
2	Increased per capita incomes, leading to increased resource consumption and demand for meat and dairy produce.
3	Increased competition for land for both urbanisation and alternative uses such as bioenergy and biorenewables.
4	Increased competition for water, amplified by shifts in availability in certain regions.
5	Potential negative effects of climate change on yields in lower latitudes.
6	Increasing competition for (and expense of) key inputs (fertilizer, fuel agrochemicals etc).
7	Slowing of increases in agricultural productivity.
8	Increased awareness of the need to protect (or improve) the provision of non-costed ecosystem services derived from land.

There have been a number of analyses both in the UK and elsewhere of the options available to address these challenges. The most significant documents from a UK standpoint are the summary outputs from the 2010 Foresight review and the report by the Royal Society in 2009[4].

Both of these documents argue forcefully for increased impetus in terms of the generation of new technology, and for its application to agriculture in the UK and worldwide.

Both reports raised the challenges surrounding the need to increase production without eroding even further the natural capital that supports the delivery of non-costed ecosystem services.

2 IAASTD (2008). Agriculture at a crossroads: global summary for decision makers. Available online at: http://www.agassessment.org/reports/IAASTD/EN/Agriculture%20at%20a%20Crossroads_Global%20 Summary%20for%20Decision%20Makers%20(English).

3 Beddington, J (2011). The Future of Farming. International Journal of Agricultural Management 1(2), 2-6.

4 The Royal Society (2009). RS 1608: Reaping the Benefits. Science and the sustainable intensification of global agriculture. 72 pp. ISBN: 978-0-85403-784-1.

Table 2 presents a summary of high-level policy actions from the Foresight report, and highlights the need to integrate new knowledge into food systems that are both more sustainable and more productive, and to ensure that policy decisions support these aims.

Table 2. Key priorities for action for policy-makers[5]

1	Spread best practice.
2	Invest in new knowledge.
3	Make sustainable food production central in development.
4	Work on the assumption that there is little new land for agriculture[6].
5	Ensure long-term sustainability of fish stocks.
6	Promote sustainable intensification.
7	Include the environment in food system economics.
8	Reduce waste, both in high- and low-income countries.
9	Improve the evidence base upon which decisions are made, and develop metrics to assess progress.
10	Anticipate major issues with water availability for food production.
11	Work to change consumption patterns.
12	Empower citizens.

Both as part of the Foresight process and subsequently, a number of reports and publications have addressed ways of changing trajectory within a UK and Northern European context[7,8,9,10].

The UK has an excellent record of innovation within agriculture, and should serve as a paradigm for how temperate countries with high population densities can respond to the challenges facing the global food system. Issues of water availability will not restrict production to the extent predicted for other countries, and UK producers have already been active in seeking to utilise appropriate technologies to improve outputs, without impacting further upon the environment[7,9].

For the foreseeable future, the UK will form part of the global food chain, but increased global demand should offer additional opportunities to UK producers, and reinforce the value of resilience of supply to processors, retailers and consumers.

There are, however, significant challenges ahead for UK producers. Current profit margins across the industry are variable[11] and flexibility in longer-term investment is restricted. Additionally, the pattern of funding for R&D that can drive technological innovation has changed dramatically over the last two decades, with a reduced participation by the State in both applied research and knowledge exchange.

5 Government Office of Science (2011). The Future of Food and Farming. Challenges and Choices for Global Sustainability. Executive Summary, 40pp. http://www.bis.gov.uk/assets/foresight/docs/food-and-farming/11-547-future-of-food-and-farming-summary.pdf.

6 In this report, agriculture should be taken to cover any land-based activity that has as its major function the production of food either directly or indirectly for human consumption.

7 Pollock, C.J. (2010). Food For Thought: options for sustainable increases in agricultural production. Foresight Regional Case Study R1. The UK in the context of Northwest Europe: http://www.bis.gov.uk/assets/foresight/docs/food-and-farming/regional/11-590-r1-uk-in-north-west-europe-agricultural-production.pdf.

8 The Conservative Party (2010). Science for a New Age of Agriculture. http://www.conservatives.com/News/News_stories/2010/09/~/media/Files/Downloadable%20Files/taylor-review-agriculture.ashx.

9 IAgrE (2012). Agricultural Engineering: a key discipline enabling agriculture to deliver global food security. http://www.iagre.org/sites/iagre.org/files/repository/IAgrEGlobal_Food_Security_WEB.pdf.

10 Crute, I. (2012). Balancing the Environmental Consequences of Agriculture with the Need for Food Security. In: Issues in Environmental Science and Technology, 34; Environmental Impacts of Modern Agriculture pp 129-149. R.E. Hester and R.M. Harrison eds. Royal Society of Chemistry.

11 Defra (2012). Total Income from Farming 2011. http://www.defra.gov.uk/statistics/files/defra-stats-foodfarm-farmmanage-agriaccount-tiffnotice-120503.pdf.

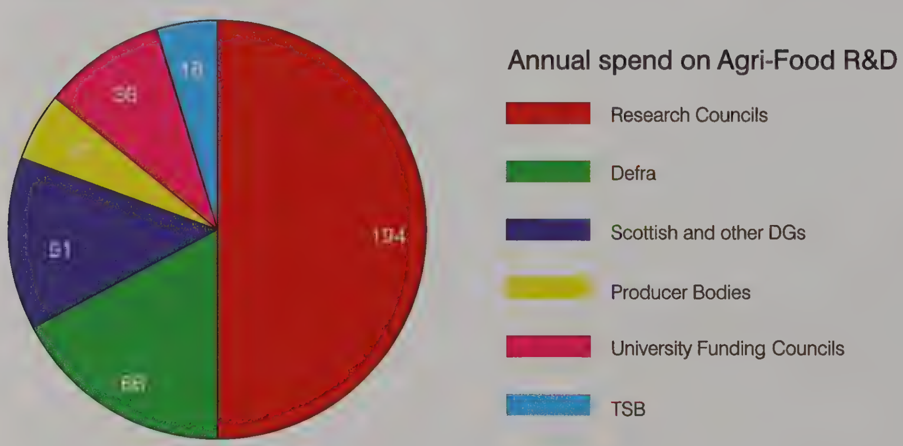
Faced with these challenges, a group representing the interests of producers and growers was established, in order to consider ways in which R&D could help UK producers to adapt to the new situation, and to plan for a future where they could play an increasing role in promoting food security whilst sustaining a viable agricultural sector.

Current investment patterns

Figure 1 shows the distribution of current expenditure on agricultural R&D in the UK. The figures are based on work by Leaver[12], but have been updated to show the contribution of the Technology Strategy Board and the contributions from university funding councils to relevant departments (principally departments of veterinary science).

There is a clear message that can be derived from this data, though it also contains a number of omissions, meaning that significant qualifications must be made. The clear message relates to the dominant position of the Research Councils (principally the BBSRC), and the relatively small contribution of the producer bodies (these include both statutory and voluntary levy organisations and a range of producer groups and agricultural charities). This strongly suggests an imbalance between the funding for basic and strategic research and that for applied research and knowledge exchange.

Figure 1. Distribution of the annual spend on UK agricultural and related research by UK agencies. The total is ca £386m.



12 Leaver, D. (2010). Agricultural research needs and priorities: survey findings from the food and farming industry. 64th Oxford Farming Conference. www.ofc.co.uk.

The omissions within these figures temper that conclusion somewhat, but do not invalidate it. The Research Councils' funding figures tend to overestimate the amount of research that has a specific objective relevant to a current industry need, because of their responsibility to maintain the health of the science base. A proportion of responsive-mode grant funding will be relevant to agriculture and land use, in that it supports the maintenance of expertise and capacity, but is not necessarily directed towards current need. Likewise, Funding Council support is directed towards maintaining HEI capacity for basic and strategic work across a broad front, but will also help to sustain the delivery of more targeted and applied studies funded by other organisations.

There are other sources of strategic funding not indicated in Figure 1, either because their main beneficiaries are not in the UK (e.g. DfID), or because the funding is competitive, variable and directed towards a changing range of objectives (eg the EU Framework Programme). UK institutions benefit significantly from these sources, and the knowledge that accrues from such funding does, over time, benefit UK producers. Finally, the contribution to strategic and applied R&D funding by the agricultural supply industry is omitted, since it is difficult to calculate, and is generally directed towards specific commercial ends. There is a limited amount of broader interchange between industry and academia that can benefit producers directly, but the current sums involved are not significant when set against the broad funding profile in Figure 1.

Two further points need to be made about the data in Figure 1. The first is that recent Defra R&D funding has had as a priority the definition and delivery of Government policy objectives, with benefit to the industry being a secondary objective. In the past, the Ministry of Agriculture, Fisheries and Food, together with Defra, acted as the 'proxy customer' for the industry according to the customer-contractor principle, and this provided a key element of the research 'pipeline' connecting basic, strategic and applied research through to delivery. With the decline in industry-relevant research funded by Defra, the TSB and Research Councils have, in recent years, had to develop other ways of targeting research more effectively to meet user needs.

Although UK Government Departments, including Defra, are now committed to supporting economic growth, continuing emphasis on the effective targeting of Research Council-funded research outputs will be important in ensuring that the recommendations from this report (Section 4) can be acted upon. Finally, Scottish Government policy has explicitly targeted the effective integration of R&D spend to benefit both government and producers[13]. The vast majority of spend on agricultural R&D by UK devolved governments is in Scotland.

National priorities are agreed and used to drive both policy and the development of R&D programmes, covering strategic and applied research linked to specific end points that have both policy and industry relevance. In Scotland there is also a structured programme of knowledge transfer and extension activity. Although most basic research carried out by Scottish institutions is still funded on a UK-wide basis, this approach does demonstrate an ability to integrate the different elements of the pipeline against a policy background where there is clear awareness of the needs of the producer community.

13 The Scottish Government (2012). Environment, Biology and Agriculture Research. http://www.scotland.gov.uk/Topics/Research/About/EBAR.

Current investment in applied producer-oriented research

Each of the producer bodies that together make up the relevant segment of R&D spending shown in Figure 1 has its own research strategy. A list of these bodies, with references to their current strategic plans, is given in Appendix 2. The size of these bodies, and consequently the size of their R&D spend, varies considerably. A broad consideration of these documents suggests that three kinds of activity are funded widely (if not universally) across the group. The first and most obvious is targeted research, development and knowledge transfer to address current problems specifically relevant to the sector. Such activities will remain a significant element of the work of these bodies for the foreseeable future, and this report does not seek to modify the independence and freedom of action of the individual boards, groups and charities in this area. It is important, however, that those commissioning R&D in such areas are fully aware of the range of research capacity in the UK that could contribute to finding effective solutions.

The second activity is to help to support or extend the market for the products relevant to each group. As with the explicitly sectoral R&D that was considered above, assessing the impact and value for money of funding in this area is the responsibility of the specific producer body.

The final area of investment is in longer-term applied research that seeks either to maintain or to develop capacity to deliver existing, improved or novel products or to reduce the costs or impacts of production. Although usually aimed clearly at maintaining or improving profitability, this research tends to be generic, is more influenced by the broad flow of new knowledge, and shows certain common features across the range of commissioning organisations.

Frequently the importance of this kind of R&D is acknowledged specifically within strategy documents, but there is often little acknowledgement of common approaches between groups or little evaluation of impact in terms of the uptake and development of new working methods across the sector. It is here that the authors of this report feel there is the maximum opportunity to add value and to influence the deployment of basic and strategic research.

Conclusions

Given that current financial constraints make it unlikely that significant additional taxpayer resources will be directed towards agricultural R&D, the key questions that emerge from an analysis of Figure 1 are:

- How can we improve the balance between support for basic, strategic and applied research within the UK?
- Could producer funding be used more effectively if the links between the various funders were improved, and if producer funding was targeted more effectively and cohesively?
- Are the priorities, targets and timescales for delivery of funding consistent with the need to meet the mid-century challenges outlined above?
- Are the knowledge exchange and extension mechanisms within the UK adequate to drive change across the sector?
- Are there changes that will be needed to promote the delivery of R&D and thereby help the industry meet its obligations to protect the environment?

II. Information-gathering and Evaluation

A brief history of Feeding the Future

In an attempt to stimulate discussion on how to maximise the benefits of UK investment in agricultural research, in May 2010 the Royal Agricultural Society of England (RASE) convened a meeting of various organisations involved in agricultural R&D.

The organisations represented at this meeting were: the RASE, the BBSRC, the NFU, the AHDB and representatives of its six Sectors (Combinable Crops, Potatoes, Horticulture, Pigs, Milk, Beef and Sheep) and the campaign group RURAL (Responsible Use of Resources for Agriculture and Land). Each organisation explained how they worked, giving a better understanding to all present of the issues and challenges faced by agriculture and horticulture.

One year later another meeting was convened, with additional representatives from the TSB, the Biosciences Knowledge Transfer Network, the British Beet Research Organisation (BBRO) and the Processors and Growers Research Organisation (PGRO), to discuss progress in addressing the challenges that were raised the previous year. Following this meeting, the RASE, NFU and AHDB agreed to develop a set of R&D priorities for agriculture and horticulture that would be developed and owned by the primary producers, and which could then be used to help direct the funders of research (BIS, the BBSRC, Defra, the Scottish Executive Environment and Rural Affairs Department (SEERAD), the AHDB and others) towards these agreed priorities.

A steering group that included the AIC was formed to take the project forward. The TSB agreed to fund and provide administrative support to this project, and a consultant (Professor Christopher Pollock CBE) was commissioned to produce the report. From the outset the Joint Commissioning Group was determined to build on the existing R&D strategies in each sector, to develop an overarching coherent strategy for primary food production. This report is the outcome of these actions.

Information-gathering process

From the start, the Joint Commissioning Group acknowledged the substantial and detailed body of existing published work, produced by individual sector groups, identifying their specific priorities for R&D and knowledge exchange. It was felt that there was little value in attempting to replicate this, and that a review of the relevant published material would yield an appropriate level of understanding of key cross-sector themes, opportunities and challenges.

A list of reference documents used in this review can be found in **Appendix 2**.

In order to validate that process and to ensure that any conclusions drawn accurately reflected the views and needs of primary producers, five stakeholder workshops were held during the summer of 2012, covering the Beef, Sheep and Grassland, Dairy, Pig, Combinable Crops and Sugar Beet, and Potato and Field-scale Vegetable sectors. A further workshop for Ornamentals and Protected Crops was held in January 2013.

Parallel consultations were undertaken with representatives of those sectors of the primary industry that were not specifically covered by the workshops. The workshops typically comprised 15-20 invited delegates from across the UK. The achieved aim was that at least 50% of the attendees should be primary producers, to make it a representative sample of the industry.
The balance of attendees was made up of advisors (nutritionists, agronomists, vets etc), sector group representatives, and representatives of the upstream and downstream supply chain, to add some context and depth to the discussions.

Each group was asked to identify the key management challenges and knowledge gaps that they felt required additional research and/ or innovation if they were to be overcome. These were then captured, discussed and prioritised by the group members.

A subsequent workshop comprising a broad range of senior industry stakeholders subsequently examined the emerging findings, and identified the key cross-sector challenges and researchable themes that would form the basis of the report's recommendations.

Emerging findings and recommendations were then presented to all workshop invitees and other selected industry stakeholders, for validation and comment prior to the completion of the report. The draft report was made available online (www.feedingthefuture.info) for comment until the end of January 2013 and a final version was agreed in April 2013.

The detailed outputs of the workshops can be found in **Appendix 3**.

III. Findings

Based on the outputs from the workshops and discussions with other interested parties, the group has sought to identify a number of generic researchable issues. Our contention is that, if these issues are addressed in a timely manner and with sufficient vigour, the outcomes would support the long-term development of UK agriculture, and would promote the 'sustainable intensification' approach envisaged by the Royal Society[4]. Outcomes would also protect and develop the capacity of the industry over a period when there will be many challenges associated with increased volatility in global markets, both in relation to inputs and products.

Although the remit of the Joint Commissioning Group related only to R&D relevant to food production, the researchable issues identified within the seven broad target areas are also relevant to the development of alternative products from the land. The eventual balance between food- and non-food production from land will depend on individual judgements conditioned by market needs and opportunities: the priorities detailed below are intended to preserve and extend capacity in all areas of production, not to restrict it.

The generic issues are grouped into eight areas, based upon the findings of the workshops. There is no attempt to prioritise these or to imply any level of hierarchy. The history of R&D in UK agriculture shows very clearly that producer benefit usually accrues from integrating scientific progress in a number of areas, to enable improvements at the agricultural system level. Accordingly, the findings set out below should be viewed as a suite of proposals that could form the basis for future concerted actions by a range of funders, providing a balanced portfolio of activity.

1 Use of modern technologies to improve the precision and efficiency of key agricultural management practices.

Develop remote monitoring, control and application technologies to optimise input use efficiency, improve animal health and welfare, sustain product quality and safety, reduce the impact of machinery traffic on land, and promote effective delivery of environmental goods and services.

Use of controlled traffic in arable crop production. The controlled traffic farming (CTF) concept is a logical extension of the existing 'tramline' approach to agrochemical and nutrient application on many broad acre crops. It goes one step further, however, by utilising a single set of wheelings for all in-field machinery traffic. The outcome is a significant cut in the level of soil compaction, a reduction in fuel use, and a cut in machinery costs per hectare.

To maximise the not-inconsiderable financial benefits that this approach offers, however requires continued investment in research and coordination between machinery manufacturers, GPS technology providers, agronomists and farmers. Additional benefit will also be gained by fully analysing the symbiotic relationships between CTF, zero-, minimal- and strip tillage, and soil structure, organic matter content and permeability.

Development of CTF should be seen in the wider context of a strategic approach to coordinating elements of precision agriculture. Linking these mechanical steps with those of sampling, mapping and site-specific applications is already possible for nutrient applications, but has the potential to be expanded and linked to wider data capture applications.

- Integrate and utilise the increasing volume of yield mapping and recording, and soil, crop and animal data, in order to develop better decision-support tools for integrated farming systems.
- Improve machine and instrument flexibility, inter-operability and applicability to the UK environment, in order to promote delivery of the above.
- Develop integrated strategic approaches to the use of nutrients and substrates to reduce environmental impact.
- Develop strategies for building/ store design that improve crop quality, animal health and welfare, and productivity.
- Develop improved and integrated pre- and post-farm-gate handling and storage solutions for perishable crops, which ensure that added value is retained and protected.

Automated weed mapping. The emergence and evolution of precision farming techniques has the potential to revolutionise the way farmers and growers address perennial challenges of crop production, such as the control of problem weeds in broad acre crops. Rising input costs, increasingly stringent environmental regulations and an ever-diminishing arsenal of effective herbicides, coupled with the build-up of herbicide resistance in target weeds, are major challenges to arable crop production.

Automated weed mapping, allowing targeted herbicide application, is one way of optimising weed control in this increasingly constrained environment. By combining state-of-the-art sensing and imaging technology with weed recognition software and GPS positioning and application control systems, farmers will potentially be able to identify and monitor specific problem areas within fields, and deploy precise, targeted control strategies that optimise product efficacy and minimise unnecessary chemical use. Whilst many of the constituent technologies already exist, albeit in relatively generic form, there is a pressing need to accelerate their development and integration, to improve the resolution and accuracy of the underpinning systems and software, and broaden the range of target weeds that can be controlled in this way.

Automating apple husbandry is an area that has attracted significant interest over recent years. However, before the orchard is even planted, automation requires a commitment to a growing system that lends itself to mechanisation. The orchard has to be planted at high density on a North/ South axis so it will develop into a 'fruiting wall' – a two-dimensional structure that will capture sunlight evenly on both sides. Pruning and thinning are areas that have been automated with a reasonable degree of success. Pruning is achieved using blades that take excessive growth off the side of the wall, although some hand work is still required each winter. Thinning is done during blossom time, with rotating nylon cords that remove unwanted flowers. It is likely that some hand work will be required later in the season.

Apple harvesting is the final challenge, but a two-dimensional wall is much easier for a robot to work with than a traditional tree where fruit will get hidden amongst the branches. Vision systems and handling systems will have to be developed, and the challenges are significant. The robot will have to be able to identify which apples are ready to pick and then handle them without either bruising them or scratching them. However, in the long term the rewards could be significant. Perhaps one day we will have robots that don't just harvest apples, they will colour and size-grade apples as they do so.

2 Apply modern genetic and breeding approaches to improve the quality, sustainability, resilience and yield-led profitability of crops and farm animals.

- Develop practical approaches for managing, curating, disseminating and using 'omics' information and related large data sets for effective precision breeding of plants and animals.
- Use better understanding of plant architecture, development and biochemistry to identify breeding targets for improved resource use efficiency and tolerance of biotic and abiotic stress in crops, now and under future climate conditions.

No-spray crops. There is an increasingly deep scientific understanding of the way that plants defend themselves against pests and pathogens; the UK is a recognised world leader in this research on the plant immune system. With targeted investment, the prospect exists to develop crop varieties with durable resistance to most of the pests and diseases which cause major losses to UK crops, and that are either not readily controlled, or that are controlled through crop-protection chemicals.

The means to identify and utilise genes conferring resistance to viruses, bacteria and fungi, as well as to insects and nematodes, is advancing rapidly through application of genomic technologies, and in particular high-throughput sequencing. Resistant varieties will be a necessary component of integrated pest and disease management, and new biotechnologies will speed up the efficiency with which such varieties can be produced.

In-built genetic resistance to any disease or pest of any crop is now within sight, and is a recognised priority for innovation required by growers of horticultural and agricultural crops.

- Generate more effective genetic improvement strategies for the ruminant sector, which identify and manipulate relevant traits and their genetic drivers, rather than emphasising specific breed improvement.

Speeding-up sheep improvement with genomics. Improvement of livestock through selective breeding is effective in all livestock species, and can make a very significant contribution to improved sustainability. The return on investment is influenced by a number of biological and market factors. Generation interval, the number of offspring per breeding animal, and the use of commercial artificial insemination are all important, as are market factors such as the precision with which commercial customers can recognise the improvements delivered by superior breeding stock.

The sheep industry is at a disadvantage in all these areas, and the uptake of current breed improvement, though highly effective, lags behind all other livestock species.

The use of genomic information is now speeding-up the rate of breed improvement in dairy cattle, pigs and poultry, and it has the potential to have a positive impact on the rate of improvement in sheep too, but the return on investment is limited by the biological factors above. A way to enable genomic selection in sheep has been developed in Australia, with the use of 'reference flocks' that record a wide range of traits, and apply genomic tools that can then be disseminated for application in breeders' flocks.

This approach is jointly funded by the Australian Government, industry and levy bodies. There is a clear opportunity to determine how such approaches can be developed to improve the economic and environmental sustainability of the UK sheep flock.

3 Use systems-based approaches to better understand and manage interactions between soil, water and crop/ animal processes

- Improve understanding of rhizosphere processes and the interactions between flows of carbon, water and nutrients under different management conditions.
- Improve knowledge and management of soil health in arable, horticultural, pastoral and mixed systems, and link this to better water and waste management.
- Improve support tools for the management of agricultural systems that optimise nutrient use and potential productivity, whilst mitigating the associated GHG emissions, other forms of diffuse pollution and losses.

Big data. Collecting, storing and mining deluges of data for commercial advantage is commonplace now in many industries; just think of the insurance industry, or the value that retailers derive from the information captured by millions of 'loyalty cards'.

Farmers and growers already collect large amounts of data (on weather, the timing of cultivations, crop and livestock performance, soil analyses, prices, sprays applied and so on), and are using increasingly automated systems. This trend is set to continue apace, as precision approaches to farming become pervasive. At the same time, the quantity and quality of data that can be and is being collected remotely is increasing rapidly. However, the industry is not yet set-up to share its data and thereby derive maximum collective value from this untapped resource; there is an opportunity here to increase competitiveness that the UK can grasp. The technology for collecting, organising, storing and retrieving vast amounts of data is already available, but it is the analysis and interpretation from which value is derived, and this is where research is required.

Data sets built over time from one farm deliver modest value to one business; but so much more value can be extracted by pooling, structuring and mining the data from thousands of farming businesses over many years. Already, benefits from data aggregation and analysis are evident in, for example, the genetic improvement of livestock. More is there to be achieved in all sectors of the agriculture industry by a structured approach to sourcing, storing and mining both land-based and remotely sensed data. Research is needed that will reveal, in large data sets, the statistical associations between variables that would previously have been invisible. This analysis will lead to new, previously unthought-of experiments designed to invalidate or confirm cause and effect. The outcome of this research is likely to be access on farms to firmly founded site- and time-specific information, on which reliable management decisions can be based.

- Develop strategies to meet the production and utilisation requirements for plant and animal protein from within UK farming systems.

Protein supply, the elephant in the room. Sustainably meeting the ever-increasing global demand for animal-based protein is perhaps the major challenge facing global agriculture over the next half century. Europe is currently less than 25% self-sufficient in vegetable protein feeds, and increasing competition from developing economies, combined with the potential of climate change to limit output growth in exporting countries, could be described as the embodiment of the 'Perfect Storm'.

Optimising the production, recovery and utilisation of vegetable protein for animal feed is a key priority for agricultural research and innovation. This is a multi-factorial challenge and the potential solutions are likely to be equally diverse.

Improving the yield, quality and consistency of protein crops, be they forages, legumes or the co-products of crops such as cereals and oilseeds grown primarily for other purposes (eg bio-fuels), is key. Bringing together developments in plant breeding, agronomy, processing, logistics and supply chain integration in co-ordinated programmes of research and innovation has the potential to significantly improve the efficiency of protein production and utilisation. Additionally, industrial biotechnology has a significant role to play in the augmentation of existing 'low-grade' protein sources through the production of synthetic amino acids.

Finally, there is a need to develop technologies and innovative supply chain solutions that can safely mitigate the risks associated with the recycling of animal protein back into food production systems, to minimise waste and increase the overall usage efficiency of this most fundamental of resources.

4 Develop integrated approaches to the effective management of crop weeds, pests and diseases within farming systems.

- Develop strategies (including novel rotations) that are compatible with continuing restrictions on the availability of approved chemical controls for crop pests, diseases and weeds.
- Continue to translate improved understanding of the genetic basis of disease resistance into breeding targets for crop plants that offer durable and sustainable control options.

5 Develop integrated approaches to the management of animal disease within farming systems.

- Promote the development of effective vaccines and control strategies for endemic and emerging animal diseases, including through understanding of the genetic basis of resistance, and translating this into breeding targets.

Improving animal health – everybody wins. Endemic infectious diseases, such as respiratory or enteric diseases, are a major source of reduced animal welfare and, through their effect on biological performance, have serious impacts on commercial and environmental efficiency. They can also reduce food quality and safety.

The diseases that are easily controlled eg by vaccines are already controlled that way. What remain are the more challenging diseases where the causal pathogen(s) are poorly understood and/or vaccine approaches are less viable. Modern high-throughput research tools, such as genomics and proteomics, open up new research opportunities to dissect the biology of these commercially important diseases. Furthermore, we now understand that selection for disease resistance/ tolerance in livestock species (potentially enabled by genomic selection tools) can make an important contribution to better disease control (along with improved biosecurity, diagnostics, vaccines and therapeutics).

Research on discovery of better methods for control of endemic diseases has been neglected in the UK in recent decades, and a new research impetus can deliver improved commercial and environmental sustainability, as well as improving animal welfare and food quality and safety. Everybody wins.

- Improve the linkage between welfare-oriented management and the utilisation of precision breeding approaches, to reduce the incidence of stress-related, non-pathogenic disorders in livestock, and any subsequent human infection disease risk.

Animal health and welfare monitoring Compromised animal health and welfare are two of the most significant causes of reduced feed conversion efficiency, and consequently increased GHG emissions when measured on a unit-of-output basis, in livestock systems. Stress, be it metabolic, pathogenic or environmental, is often linked to immune suppression, and the early detection and mitigation of stress factors and their physiological consequences is fundamental to sustainable livestock production.

Better understanding of animal behavior and the interrelationships between the animal and its environment, be it housed or at pasture, along with the ability to monitor and analyse a broad range of physiological and environmental parameters in large numbers of animals, and in a cost-effective way, is key. This will require the development and integration of a range of technologies that can independently monitor and analyse behavioural and physiological trends, identify risk factors and developing health and welfare issues on a real time basis, and provide appropriate decision support to managers.

Advances across a range of sensing technologies, eg motion sensing, metabolic marker detection and the emergence of 'in-animal telemetry', along with the ability to reliably capture, analyse and utilise the large volume of data that they generate, offer massive potential to optimise animal health and welfare, whilst driving sustainable improvements in productivity and environmental performance across all livestock sectors.

6 Develop evidence-based approaches to valuing ecosystem service delivery by land users, and incorporate these approaches into effective decision-support systems at the enterprise or grouped enterprise level.

- Develop new models for integrated mixed farming, based around co-location of specialist enterprises, optimising value from crop diversification and co-products, and thereby generating a safe and sustainable 'circular agricultural economy'.
- Promote development of the knowledge base, to provide understanding of the mechanisms by which ecological networks deliver ecosystem value through inter- and intra-species diversity.
- Develop (in concert with other countries in the EU and elsewhere) robust tools for measuring, valuing and monitoring ecosystem service outputs from a range of farming systems. Incorporate these into advanced management strategies and effective decision-support tools.

Phosphorus recovery from waste streams[14]. Concerns around the potential for soil phosphorus (P) balance, the sub-optimal use of it as an essential and increasingly expensive nutrient, the increased risk of pollution in both ground and surface water, and the ultimate loss of the nutrient from the system have led to investigations into the viable recovery of P from manure waste streams. Various potential waste stream sources exist, including the dairy sector, but also human, pig and poultry (HPP) waste.

The efficient recycling of P from HPP waste will require a level of industrial treatment to enable it to be re-used in an economically viable manner, away from the waste source. Research into the use of microwave pre-treatment of slurries has shown that it is possible to 'unlock' P from the organic fraction of the manure, allowing it to be recovered in concentrated mineral form. A further advantage of this process is that the residual organic fraction of the manure stream not only contains less potentially polluting P, but has proven to be more rapidly broken-down by anaerobic digestion. The development of bio-reactors to release mineral P in its organic form, using carbon as a bacterial feedstock rather than simply generating biogas as an output, has the potential both to improve the efficiency and reduce the capital cost of this process significantly.

Improving the efficiency and reducing the cost of such processes, to the point that they can be commercially deployed, will require considerable investment, but they have the potential to yield significant long-term economic and environmental dividends.

http://content.alterra.wur.nl/Webdocs/PDFFiles/Alterrarapporten/AlterraRapport2158.pdf.

- Encourage investigation of the wider plant genetic resource base and its role in the mitigation of GHG emissions and diffuse pollution.
- Develop regional models to assist policy-makers to manage the relationship between the delivery of essential ecosystem services and changes in the patterns of land ownership, tenure and use.

14 Alterra (2010). 'Phosphorus recovery from animal manure: technical opportunities and agro-economical perspectives'

7 Extend the training, professional development and communication channels of researchers, practitioners and advisors, to promote delivery of the targets above.

Up-skilling the industry. There is a shortage of young farm managers who have the skills required for the increasingly technological and commercial challenges of modern agriculture. This is an industry-wide issue, as even the largest farming organisations lack the resources to develop and run effective management training schemes on their own.

The vision is to have well-trained professional managers who can meet current and future technical and business requirements. For example, there is a need to develop farm management training schemes involving groups of farming businesses which are accredited by recognised agricultural universities, colleges and other professional organisations.

The trainee farm managers, many of whom would already have a degree or diploma, would gain experience in different businesses and sectors of agriculture. The farming businesses would benefit from a pool of enthusiastic young people who in time would gain wide practical experience, and the accrediting organisations would develop closer links with agricultural businesses.

- Work with HEIs, RCUK, BIS and the wider agribusiness/ advisory sector to identify key research/ technical skills that are in short supply or absent in the UK. Develop approaches to improving the supply of graduates and postgraduates, with relevant training both as researchers and as technical support specialists for agri-business.
- Work with HEIs, FEIs and others to develop CPD across agri-business that will integrate with and support existing extension activities.
- Develop structures to facilitate the greater use of practical 'demonstration' techniques within a wider training scenario.
- Develop strategies to ensure effective knowledge exchange between researchers and advisors to improve understanding and maximise development and innovation opportunities.

8 Improve the use of social and economic science to promote the development, uptake and use of sustainable, resilient and profitable agricultural practice that can deliver affordable, safe and high-quality products.

- Develop a series of 'good practice' case studies for effective knowledge exchange between researchers, advisors and farmers.
- Evaluate common features so that future research can be commissioned that maximises the likelihood of effective delivery.
- Investigate further options to identify 'best practice' from wider dissemination of research carried out by the agricultural supply industry, without compromising company profitability.
- Identify the potential economic and social constraints on farmers that might slow or prevent uptake of new knowledge, including the effects of public opinion, and how these constraints might alter over time.
- Carry out socio-economic evaluations of the costs of new technology and the ways that it might be introduced.

IV. Recommendations

The cost-effective and efficient management of applied agricultural research, to deliver an increasingly wide range of benefits in a way that directly supports producers, will not be straightforward. Retrospective analysis of previous paradigm shifts in agriculture shows a number of instances both of 'science push' (eg the use of dwarfing genes in cereals) and 'industry pull' (eg the incorporation of silage rather than hay into ruminant rations), so any long-term vision for R&D management must be able to sustain both types of advance. A brief analysis of successful programmes from other countries (presented as a series of case studies in Appendix 4) indicates that the likelihood of success is enhanced if the following four criteria are met:

- Involvement of producers (in partnership with other funders) in defining and funding programmes, in evaluating bids, and in overseeing the strategic management of the programme.
- The provision of high-quality, independent scientific advice at an early stage in defining programme parameters, particularly in relation to duration and level of funding.
- The existence of (or at least support for the development of) a clear route by which the results can be developed through translational research and knowledge exchange, to ensure effective dissemination to a user community that is able and willing to act upon them.
- A commitment by all parties to ensure that widespread uptake is not constrained by lack of training, advice or availability of skilled manpower.

In order to promote this programme of long-term strategic and applied research, the Joint Commissioning Group presents five specific recommendations for the attention of public and private research funders and providers.

A. Levy bodies and other producer groups should consider ways in which they could help establish joint programmes based on the recommendations above, and leverage additional investment from the Research Councils, Government Departments, the TSB, the EU and other funding agencies. Such programmes should be defined, funded and delivered in a manner that meets the criteria set out above. They should also be framed to maximise the options for research providers to obtain further funding from the EU, other UK Government Departments or industry, providing that this does not jeopardise delivery of the main aims of the programme. All the criteria defined above should be fully addressed at the planning and development stage prior to any producer agreement to fund.

B. The Research Councils, Government Departments and, where appropriate, HEIs and Research Institutes should seek broader representation from producers on relevant councils, boards and committees. Levy bodies and other producer groups should nominate representatives who will work to foster long-term, integrated approaches to the challenges outlined in this document, rather than promoting narrow sectoral interests.

C. Given the increasing policy emphasis on land-based issues covering food production, alternative land use, climate change adaptation and mitigation, and the protection of natural capital, there needs to be an integrated consideration of options to improve the provision of advice, training and skilled manpower at a UK level, both in terms of producers and of the skills within the R&D and consultancy base. Effective delivery of more sustainable production approaches that do not compromise profitability will only impact on meeting Government targets if uptake by producers is much more widespread than has been achieved in the past. Although

there are differences between the UK and devolved governments in some respects, this is a challenge that is UK-wide. The Joint Commissioning Group welcomes the report on Agricultural Technology, from Defra and the Office of Life Sciences within BIS. Levy bodies have considerable experience both in the dissemination of new knowledge and in the measurement of effectiveness of uptake, which will be very relevant to the Departments' policy deliberations.

D. The policy and strategy implications associated with the research recommendations in this report should be considered holistically both by government and the funders of basic and strategic research. In governmental terms, there is a need to ensure consistency of policy and approach between different Departments with an interest in land and water use, food and energy production and the protection of natural capital. A coherent UK viewpoint will help deliberations at an EU level over the evolution of a regulatory regime that currently lacks both focus and consistency.

E. In terms of the funders of research, thought needs to be given to how future strategic decisions over 'blue-sky' and responsive-mode funding can be managed to protect the UK capacity for scientific excellence, whilst addressing skills shortages in key areas such as soil science and applied crop sciences. A more appropriate balance between fundamental and applied research, and closer interaction between science, advisory and farmer communities, must be encouraged. Effective mechanisms must be developed to grow excellence in areas of strategic need as well as new science opportunity. Addressing this challenge will require dialogue between the Research Councils, relevant parts of the university sector, and other funders.

V. External Influences that Might Affect the Development and Uptake of Innovation

The findings and recommendations of this report are predicated upon two main principles. Firstly, that the forecasts for world demand for food and other products of land use are broadly in line with those discussed in the Foresight review[6], and secondly that there is general agreement over the need for the UK agricultural sector to adapt to these changing circumstances. These principles were considered in detail at the last Joint Commissioning Group workshop on cross-sectoral issues. The positive drivers summarised below flow from these principles, and would be expected to have beneficial consequences for UK producers:

- Rising global demand for food.
- Increasing global prosperity driving higher consumption of meat and dairy products.
- Increasing political significance in Europe given to issues of food security.
- Potential beneficial effects of climate change on some elements of UK production.
- Increasing political pressure to improve efficiency and reduce waste/ losses.
- Better opportunities to integrate both R&D and production systems across land use, including the production of food, energy, and bioproducts, will generate new business opportunities.

However, the workshop also identified a number of potential drivers that could impact negatively, at least in the short- to medium-term, on the effective development of the industry, and consequently on the implementation of the priorities and recommendations within the report. These are summarised below, and cover concerns about the ability of producers to adapt and invest whilst under short-term financial pressure, the over-rigid regulatory regime for European producers, and the potential sensitivity of the industry to sudden shocks such as emerging diseases and input price fluctuations:

- Altered patterns of land tenure and increased contract farming driving short-termism.
- Insufficient profit for producers preventing or reducing long-term investment.
- Reduced meat consumption in developed countries leading to loss of markets in the short term.
- Inconsistencies in and costs of EU regulatory system preventing uptake of appropriate technologies and hastening loss of existing technologies.
- Pressures to reduce emissions and diffuse pollution leading to export of production. The need to recognise the 'irreducible minimum agricultural carbon footprint'.
- Emerging animal diseases not being managed effectively, due to insufficient investment in new products and vaccines.

The workshop also identified a number of operational challenges that could impinge on delivery of the report's recommendations. In the main, these have been addressed in detail within the body of the report, with the exception of the final comment relating to consumer confidence:

- Ensuring that innovation reaches further down the producer profile than in the past, in the absence of a UK-wide extension system.
- Ensuring buy-in from producers for a shift in emphasis towards the longer-term.
- Maintaining R&D investment at a level appropriate to the UK's largest business sector.
- Improving engagement between key stakeholders in the establishment of longer-term R&D priorities.

- Improving integration of Member State- and EU-funded R&D, to maximise value and improve innovation.
- Re-establishing consumer trust and loyalty to UK producers.

The need to re-establish consumer trust and loyalty at the producer level, whilst important, lies outside the particular remit of this report. However, there is an increasing body of social and economic research relating to the marketing and supply of agricultural produce at a range of scales, and there may be value in a broad analysis of the outcomes of this research.

VI. Next Steps

In order to implement the findings and recommendations of this report, the actions listed below will be required. These are all matters of some urgency, given the development of the BIS/ Defra Agri-Tech Strategy.

1. Representatives of the producer funding organisations should consider Recommendation A, and seek agreement on the modalities for consolidated funding of longer-term generic research, whilst also considering the development of long-term solutions for the provision of applied translational research and knowledge exchange.
2. Following this, discussions should take place with other relevant funders (the Research Councils, Government Departments, the TSB etc) to agree a priority order and timelines for addressing the research priorities, investigate joint or matched funding opportunities, and establish procedures to specify, commission, monitor and disseminate outputs.
3. Simultaneously with 1, representatives of the producer funding organisations should contact the BBSRC, NERC and other relevant organisations with proposals not only to increase producer representation, but also develop new interactive knowledge flow systems and networks.
4. The development of the Defra/ BIS Agri-Tech Strategy offers an excellent opportunity for producers to follow-through on issues relating to knowledge transfer, and re-establish the relevant skills and expertise base within the UK.
5. In terms of promoting a consistent approach within government to sustaining production agriculture as an essential foundation for the UK food and drink industry, and achieving sustainable intensification, the Joint Commissioning Group should work with other interested parties to develop common positions on research and knowledge exchange matters.
6. The Joint Commissioning Group should discuss with the BBSRC the implications of recommendation E. Any significant changes in the way in which responsive-mode funding is delivered will also have to be debated by the relevant research providers, and it is probably not realistic to expect swift progress in this area. In consequence, the Group should identify any priority areas where skills shortages are currently constraining progress.

VII. Concluding Remarks

This report has attempted to delineate the challenges facing producers in adapting to 'sustainable intensification'[3]. It has recommended that producer organisations need to change the way in which they engage with and partner other research funders in order to maximise the likelihood that cutting-edge science (the development of which is one of the strengths of the UK science base) can be deployed effectively in support of a significant industrial sector.

Re-establishing continuity will also generate other opportunities for researchers to gain impact, through deploying new approaches and technologies outside the UK, and by enhancing their ability to develop, implement and monitor policies that are in tune with current views about multifunctional land use.

The role of government is essential in expediting such change and helping to ensure effective delivery, but above all it requires a level of acceptance from within the producer base that significant changes are needed as a matter of some urgency.

The UK has an opportunity to develop as a paradigm for how small, developed countries with high population densities can play a significant part in addressing the challenges facing the global food system, and this report is intended to promote this long-term objective.

VIII. Appendices

Appendix 1.
Membership and affiliation of the Joint Commissioning Group.

Professor Ian Crute CBE is Chief Scientist of the Agriculture and Horticulture Development Board, which he joined from Rothamsted Research in 1999 after 10 years as institute Director. This followed 25 years in Horticulture Research International as a research leader in plant pathology, and a Head of Department and Director at Wellesbourne. Ian's scientific contributions have led to him receiving several awards, and are recorded in over 160 publications. He was a Member of the Lead Expert Group for the 'Global Future of Food and Farming' Foresight project, and currently serves on several boards and committees connected with science and innovation within the UK agri-food sector.

Dr Andrea Graham joined the National Farmers' Union as their Countryside Adviser at their Headquarters in Stoneleigh in 2007, following 18 years in agricultural research. She has been involved in developing national policy and advice for the NFU on many key countryside issues including agri-environment schemes, wildlife and biodiversity, landscape, forestry and woodland, and the design and implementation of the Campaign for the Farmed Environment. For the last year, she has been the NFU's Acting Chief Science and Regulatory Affairs Adviser. She is currently the NFU's Chief Land Management Adviser, taking a policy lead on knowledge exchange and the application of science and innovation on farms, sustainable intensification, and the Green Food Project.

Paul Rooke is Head of Policy, External Affairs for the Agricultural Industries Confederation (AIC). He is also the Sector Head for the AIC Crop Marketing and Seed Sectors, as well as managing the Confederation's Contract and Arbitration services. He represents the AIC on a range of government and stakeholder bodies in both the UK and EU, is a member of the Red Tractor Crops Board and the industry body SCIMAC, and is a founder of the All Party Parliamentary Group on Science and Technology in Agriculture. He was also a member of the FSA's Steering Group on the proposed national GM Dialogue. He joined the AIC's predecessor organisation, UKASTA, in 1992, having completed a BSc (Hons) degree in Agriculture at Harper Adams. Paul also has a postgraduate qualification in law from Westminster University.

David Gardner joined the Royal Agricultural Society of England as its Chief Executive in April 2012. His role is to take the Society back to its roots, based upon 'Practice with Science'. He is currently developing a technology transfer initiative based around the emerging technologies that will shape agriculture over the coming decades. Prior to joining the RASE, David enjoyed a long career with the Co-operative Farms who he joined as a graduate after studying at Seale Hayne. During his time with the Co-operative Farms, David held a number of senior positions including Head of Fruit Operations, and Manager of Stoughton Estate in Leicestershire. He has considerable experience in the combinable, dairy and fruit sectors. In 2010 David completed a study funded through a Nuffield Arden scholarship, investigating 'The Appliance of New Science and Frontier Technologies to Transform UK Agriculture'.

Jim Godfrey OBE is an arable and pig farmer from Lincolnshire. Jim is a non-executive director of the National Institute of Agricultural Botany (NIAB) and Lincolnshire Rural Support Network, chairman of the Technology Strategy Board's Sustainable Agriculture and Food Innovation Platform, and a member of the BBSRC Council, the Commercial Farmers Group, the Nuffield Farming Scholarship Selection Panel, the Centre for Excellence in UK Farming, and the International Rice Research Institute. Jim is a former chairman of the Potato Marketing Board, the Scottish Crop Research Institute, Sentry Farming Group plc, the International Potato Centre, and the Alliance of the 15 Research Centres of the Consultative Group on International Agricultural Research (CGIAR), and he is a former non-executive director of the Rural Payments Agency.

David Alvis is a Lead Technologist with the Technology Strategy Board, with co-responsibility for the Sustainable Agriculture and Food Innovation Platform. He represents the TSB as part of the GO-Science Food Research Partnership, and is a member of the FRP Research Translation sub-group and the Dairy Science Forum. David is a dairy farmer's son from Somerset and has a BSc in Agriculture from Wye College, University of London and an MBA from Cranfield School of Management. He is also a Nuffield Scholar. He has over 20 years' management experience in the industry, ranging from farm management to commercial and general management roles, in the fresh produce sector with Greenvale AP and in the agricultural supply sector with the Roullier group. David worked for the TSB as a consultant from February 2010, and in May 2012 joined the organisation as Lead Technologist on a part-time basis, dividing his time between his TSB role and his own business, Winstone Agribusiness Consulting Ltd.

Calum Murray is a Lead Technologist with the Technology Strategy Board, with co-responsibility for the Sustainable Agriculture and Food Innovation Platform. He represents the TSB on the Programme Coordination Group as part of the BBSRC's Global Food Security initiative and the International sub-group of the Food Research Partnership, and he is a member of the LEAF Advisory Board. Calum graduated from Aberdeen University with an Honours degree in agriculture in 1982. His career started with ADAS in Suffolk, and he moved into farm business consultancy before joining the SAC back in Scotland in 1990. In 1995 he was appointed by the Bank of Scotland as national agricultural specialist. In 2006 he was appointed Regional Director for NFU Mutual Finance, a Bank of Scotland JV. Following the merger of HBOS and Lloyds, Calum joined the Technology Strategy Board in February 2010.

Professor Chris Pollock CBE (Report Editor) was Director of the Institute of Grassland and Environmental Research in Aberystwyth from 1993-2007. For many years, Chris has been involved nationally in agriculture and land use. He chaired the Scientific Steering Committee for farm-scale evaluations of GM crops, the Defra Research Priorities Group for Sustainable Farming and Food, and the Agriculture, Food and Veterinary Science panel for the 2008 RAE. He is currently chair of the Advisory Committee on Releases into the Environment.

Appendix 2.
Reports and strategy documents used in the evaluation phase of this study to assess the breadth and coverage of current applied R&D in the land use sector.

Dairy Co

http://www.dairyco.org.uk/farming-info-centre/research-development.aspx

http://www.dairyco.org.uk/library/research-development/environment/dairy-roadmap.aspx

http://www.dairyco.org.uk/library/corporate/business-plans/business-plan-2010-2013.aspx

English Beef and Lamb Executive (EBLEX)

http://www.eblex.org.uk/research/index.aspx

http://www.eblex.org.uk/publications/research.aspx

http://www.eblex.org.uk/documents/content/publications/p_cp_
changeintheairtheenglishbeefandsheepproductionroadmap.pdf (Road Map 1)

http://www.eblex.org.uk/documents/content/publications/p_cp_testingthewater061210.pdf (Road Map 2)

http://www.eblex.org.uk/documents/content/publications/p_cp_down_to_earth300112.pdf (Road Map 3)

British Pig Executive (BPEX)

http://www.bpex.org.uk/R-and-D/default.aspx

http://www.bpex.org.uk/environment-hub/climate-change/PigIndustryRoadmap.aspx -

Home Grown Cereals Authority (HGCA)

http://www.hgca.com/content.output/5086/5086/Funding%20and%20Awards/Funding%20and%20
Awards/Research%20and%20knowledge%20transfer%20strategy.mspx

Potato Council (PCL)

http://www.potato.org.uk/node/214 -

Horticultural Development Company HDC

Overarching strategy http://www.hdc.org.uk/over-arching-strategy -

Bulbs and outdoor flowers http://www.hdc.org.uk/sectors/BOF_RandD.asp

Field vegetables http://www.hdc.org.uk/sectors/FV_RandD.asp

Hardy nursery stock http://www.hdc.org.uk/sectors/HNS_RandD.asp

Protected edible crops http://www.hdc.org.uk/sectors/PE_RandD.asp

Soft fruit http://www.hdc.org.uk/sectors/SF_RandD.asp

Tree fruit http://www.hdc.org.uk/sectors/TF_RandD.asp

Campden BRI publications

'Scientific and technical needs of the food and drink industry – 2012-14'
http://www.campden.co.uk/research/strategy.pdf

House of Lords

European Union Sub-Committee D 'Innovation in EU Agriculture' – published July 2011 (19th Report of Session 2010-12)

HM Government

The Natural Choice – securing the value of nature. UK National Ecosystem Assessment
http://uknea.unep-wcmc.org/

Commercial Farmers Group (CFG)

Priorities for Agricultural and Horticultural R&D (2009)

Environmental Sustainability KTN

'Environmentally Sustainable Agri-Food Production' (2012)

Defra Green Food Project Report

http://www.defra.gov.uk/publications/2012/07/10/pb13794-green-food-project/

Hybu Cig Cymru (HCC) Welsh Meat Roadmap

http://hccmpw.org.uk/medialibrary/publications/HCC%20Sustainable%20Red%20Meat%20Roadmap%20English%20LR_1.pdf

Institute of Agricultural Engineers (IAgrE)

http://www.iagre.org/sites/iagre.org/files/repository/IAgrEGlobal_Food_Security_WEB.pdf

Society for General Microbiology

http://www.sgm.ac.uk/PA_Forms/FoodPS_Web.pdf

British Beet Research Organisation (BBRO)

http://www.bbro.co.uk/science

Appendix 3.
Collated workshop outputs

Beef, Sheep & Grassland Workshop – Key Challenges & Priorities

Husbandry & Nutrition		Genetics		Health & Welfare		Farming Systems		Engineering & IT	
******	Additives to improve FCE/ gut health	*********	Breeding for disease resistance	*********	Vaccine development (blue tongue, TB, Schmallenburg etc)	******	Livestock benefits on arable farms	********	Improved EID technology & portable systems of livestock record keeping
*****	Improving effectiveness of AI	********	Rumen metagenomics	******	Biosecurity & disease eradication	***	Balancing production and environment (ecosystem services)	*****	(Automated) recordingof phenotype information
*****	Grass as a crop - selection, soil & nutrient management, utilisation	****	Eating quality	******	Lameness, locomotion & longevity	***	Optimising land use	**	Databases that communicate with each other/ industry-wide IT system integration
****	Use of co-products & human food chain bio-recycling	****	Grass & legumes to replace soya	***	Identification of parasites pre clinical symptoms	***	Matching appropriate animal breeds to farming system	*	Electronic carcase classification
***	Culling for the right reasons	***	GM hi-sugar, N-fixation, drought tolerance	**	Trace elements & animal immune system response	*	Alernative forage crops to grass		Market information & risk management tools
**	Understanding key business drivers & management trade-offs	**	Growth rate & feed efficiency	*	Volatile monitoring of AH		What do animals contribute to soil		Tools for pre-slaughter assessment of animals
**	Manure & nutrient management for grass	**	Genetic reduction of enteric methane	*	Novel diseases		Environmental schemes vs liver fluke control - tensions		Measuring & mapping grass growth
**	Optimum slaughter age	**	Neo-natal survival & maternal instinct	*	Worm/ fluke diagnosis & control		Catchment management of contaminants - prediction models		Tools to optimise economic & environmental decision-making
*	Manipulation of nutrition to improve consumer health	**	Identification of desirable traits in traditional breeds - genomic markers		External parasite control		Zero grazing systems		
*	Fallen stock management	**	Functional trait markers		Disease resistance in animal populations		Is stratification structure appropriate for 2030?		
	Feeding - nutrient requirements for growing animals	**	Easy care breeds/ composites		Managing antimicrobial resistance		Systems for a volatile climate		
	Soil sampling inc trace elements for livestock species	*	Targeted breeding programmes for UK systems & markets		Rumen function		Indoor vs outdoor lambing		
	N-sensors & CTF for grassland	*	Balanced breeding		Midge control to control diseases				
	Measuring grass quality & performance/ growth		Breeding for functional traits rather than breed types - composites/ hybrids						
	Hormone implants & ionophores		Lean meat production efficiency						
	Alternative protein sources		EBVs						
			Carcase uniformity						
			Mastitis resistance						
			Heritability of reproductive performance						
			Sexed semen - improved performance						
			Cloning? Where will it make a difference						
			Genetic modification of animals to produce medicinal/ pharmaceutical products						

Pig Sector Workshop – Key Challenges & Priorities for Research

Husbandry & Nutrition		Genetics		Health & Welfare		Farming Systems		Engineering & IT	
10(29)	Maximising exploitation of current genetics	1 (9)	Novel breeding technologies (GM, genomics)	12 (37)	Managing health & disease	15 (24)	Training & investment in staff at individual farm and industry level	2(5)	Improving efficiency measurement
5(14)	Feed efficiency	***	Improving FCR	7(13)	Balancing welfare with productivity	1(5)	Improving outdoor production systems	*	Measuring DLWG & FCR in field
******	Improving FCR	***	Taste, flavour & texture	*******	Managing animal health	*******	Investment in improving building stock/ quality	*	Auto-monitoring & control of feeding
******	Reducing pre-weaning mortality	***	Sow fertility & fecundity	*****	Tail biting/ aggression in finishing pigs	*****	Building design for increased performance & welfare	*	Precision environments
******	Increasing productivity per sow (weaned pigs/ sow/ yr)	**	Disease resistance	***	Endemic disease control	**	Environmental management/ constraints	*	Automated monitoring of piglet prodn to reduce mortality
**	Utilisation of alternative feeds			***	Welfare constraints & pig behaviour	**	Planning regulation		
*	Alternative protein supplies			***	Freedom farrowing systems				
				**	Emerging disease identification and management				
				*	Salmonella				
				*	Sow aggression				
				*	Sow longevity				
				*	Swine dysentery				
				*	Satiety in gestating sows				
				**	PRD				

Dairy Sector Workshop – Key Challenges & Priorities for Research

Current Husbandry									
Fertility		Lameness		Mastitis		Feeds & Feeding & Youngstock Rearing		Health & Welfare	
*******	Early embryonic death genetic, nutritional, health status	****	Lameness/ pain detection	****	Genotype links to treatment regime - stratified management	*****	Neo-natal & pre-ruminat management	******	Immune system function/ suppression
*****	Cow stress - measurement	*	New DD treatments formalin/ copper sulphate	***	In-line detection automated	****	Liver damage & fatty liver	******	Johnes
****	Submission rate vs conception rate (declining CR - why?)		KE adoption of current best practice	***	Multi-modal & interptetation	***	Calf & heifer rearing	*****	Better diagnostics
**	Once-a-day milking		Digital dermatitis - pathology, resistance & vaccination	**	Alternatives to antibiotics	**	FCE	***	Anti-microbial resistance
**	Endemic & sub-clinical disease		Why do some cows not get lame	**	Diagnostics - real-time & stratified therapy	**	Rumen modifiers	**	Social & behavioural requirement of cows - modelling building design
*	Physiological drivers of (in)fertility		Health economics	**	Biological control - cow, teat, environment	**	Synthetic amino acids	*	Persistent & multiple vaccines
*	Nutritional drivers of fertility & negative energy balance		Cow behaviour	*	Cow comfort & environmental hygiene	*	Supplementing grazing and balancing forage variability		Scours
	Herd synchronisation for UK		Floor surface v lameness	*	Self-curing	*	Optimising feed utilisation		Building design
	Transition management & management grouping		Early life development	*	Sub-species strain		Colostrum quality		Vaccine technologies
	Measurement of data		Plastics to treat lameness		Vaccination (Staph Aureus)		Colostrum replacers		Animal immunity/ measurement
	Involuntary cull rates		Genetics & nutritional links - digital cushion		Anti-inflammatories vs antibiotics		Weaning strategies		
	Extended lactation & calving interval - LDY vs lact yield		Maintaining sole thickness post calving		Secondary costs of mastitis		Rumen development		
	Aids to heat detection & submission rate		Get vets, farmers & foot-trimmers to work closer re lameness management				Measuring youngstock development		
	Breed vs hybrid						Self-feed systems for large herds		
	Late lactation vs transition management						Feeding different breeds		
	Building design & cow environment/ comfort						Innovative ways of delivering nutrients to cows		
	Maternal recognition of pregnancy						Enzymes for better feed utilisation		
	Social environment & stress						Sub Acute Rumen Acidosis		
							Minerals Cu, Mo, Se, I		

Genetics		Farming Systems		Engineering & IT		Forage Production		Environment & Social	
**********	Phenotypes remote/ automated sensing	****	Skills requirements for 2030	**********	Measurement & sensing of cow stress	*****	Home-grown protein	****	De-watering waste streams
***	Resistance to disease	***	Matching systems to geography/ regions	****	In-line progesterone testing	***	Soil health		Definition and measurement of welfare
***	IVF & cloning	**	Data & models for farming systems	***	Prediction of calving date & time	**	Maximising dry matter yield		Social environment & stress
***	Embryonic loss	**	Food Security & Ruminants	***	Early lameness detection technology	*	Understanding soil organic matter		UK & young people into farming
**	Feed intake & FCE	*	Organic systems	*	Real-time sensing of soil properties	**	Palatability & intake characteristics		Changing perception re commercial-scale livestock systems
**	Collecting data, data islands sharing		Understanding cow behaviour - designing buildings and dairy systems accordingly	*	pH bolus	*	Legume persistance		Methane emissions
**	Genetics for heat expression		Social research - how to get messages to farmers	*	Decision support systems for slurry management		Phosphate management		Better use of wastes
**	Novel milk		Simple systems	*	Non-invasive cow side tests		Trace-element management		Retaining nutrients that leach
*	Genotypes & drug response		Valuing ecosystem services	*	Heat detection		Making forage in poor conditions		Reduced manure odours
*	Selection for specific production systems		On-farm systems for measuring ecosystem service	*	In-line mastitis detection		Selection of forage varieties		Carbon sequestration by grass
*	Consistent values of reliabilities		Diversity of systems		Decision support tools		Measuring DMI at grass		Short/ long-term carbon cycles
*	Closed loop data collection & use		Buildings		Collection & analysis of historical data re mastitis		Better forage analysis		Sand recycling systems
*	Raised genetic merit for fertility		Labour efficiency		Driverless feeder wagon		Breeding for RUE		Environmental management systems to make planning less subjective
	Digital dermatitis index		Process flow				Forages for extreme climate		Water as a resource
	Cow families & mastitis		Managing heat stress				C4 genes in grass		Resource planning tool
	GM resistance to mastitis		Energy efficiency				Nitrogen-fixing grasses		Carbon footprinting tool
	Sexed semen		Cost-effective dirty water cleaning systems						Reducing fossil fuel use
	Digital cushion		Water quality assessments						Understanding Nitrogen-fixation by legumes
	Making bull calves more profitable		Moisture-free environment						Optimisation and storage of manure nutrients
	Heterosis - benefits		Welfare assessment						Biogas from slurry
	Managing genetic resources/ diversity		Understanding relationship between building design & fertility						Beef from dairy herd - not shooting bull calves
	Genetics for forage utilisation								Movement of bacteria/ genetic info from farm to other environments
	On-farm genomics								Biosecurity at scale
	Rumen metagenomics as a driver of resource use efficiency								Adaptation to climate change

Potatoes & Field Scale Vegetable Workshop – Key Challenges & Priorities for Research

Crop Husbandry		Genetics		Environment & Social		Farming Systems		Engineering & IT	
****************	Availability of crop protection products	******	Availability of marker-assisted breeding	*****	Matching ecology with production	*********	Rotational soil & nutrient management	***	Post-harvest detection of internal defects
******	Crop maturity control (brassicas)	*****	Introducing N-fixation in other crops	**	Managing effective biodiversity/ beneficials	**	Rotational solutions to persistent issues	***	Robotics
****	Weed control	****	Potato blight	***	Sources of major nutrients	**	Alternative weed control barriers	***	Advanced storage & grading systems
****	Bruising	****	Drought resistance	**	Energy use/ climate change	*	New crops for the UK	**	IT to diagnose problems - remote sensing
***	Nutrients	****	Storage - sprout control	*	Efficient use of water	*	Crops to aid weed/ pest control	**	Mechanical harvesting of veg
***	New diseases/ invasive species	***	Yield	*	Meeting consumer requirements	*	Urban farming	*	Precision weeders
***	Light to propagate veg plants	***	Pest & disease resistance/ tolerance	*	Low GI potatoes		Legacy left by cereal farmer	*	Reducing management hours - MIS
***	Spear rot in brassicas	**	Nutritional quality (diet/ health)	*	Introducing predators into the field	*	Benefits of mixed farming systems	*	Better automated vision grading
**	Virus prevention	**	Improvements to enable mechanical harvesting	*	Non-water control of common scab		Risks to mixed farming	*	Educating next generation
**	Post-emergence herbicides	**	Shelf life	*	Targeting spray applications		Value of compost etc	*	Soil nutrient/ N analysis
**	Soil management	**	Gene identification in a broad range of plants	*	Waste utilisation for energy		Anaerobic digestion		Indicator plants to understand growth
*	Aphid control	*	Soil biology	*	Landscape level management of water		Vertical farming		Storage v transport
*	Water/ irrigation management	*	Resilience over range of environmental conditions		Pest horizon scanning		Companion/ perma-cropping		Plants & growing systems to make robots work
*	Alternative (non-peat) substrates for transplants	*	Adaptation to higher temps (climate change)		Social acceptability of new science		Short-term issues rented land		CTF for vegetable production
*	Crop dessication	*	Smart plants		Phosphate utilisation		Green manures		Sensors for selective harvesting
	Crop uniformity		What initiates what in plants (including weeds)		Energy use for protected production				Automated phenotypic data collection
	Crop establishment		Resistance to club root		Regulatory pressure for pollution control				Contaminant removal/ reduction
	Potato nematode control		Nutrient stress resistance		Keeping inputs/ run-off in the field				Atmosphere control by crops
	N-optimisation		Flavour		Novel uses of by-products				Unknown unknowns
	Constraints of RB209		Public acceptability of new varieties		Precision landscape planting				ID of pathogens (food poisoning)
	Snails in peas		Quicker integration of traits into commercial varieties		Headland management for biodiversity				
	Bio-fungicides		Bolting control		Efficacy of organic weed control in different conditions				
	Skin blemishes		Improving N-fixation in legumes						
	Sugar levels potato storage		Oxidisation post-harvest						
	Potato blight		Crop programming in a changing climate						
	Weed control - non chemical								
	Season extension								
	Downy mildew								
	Fusarium								
	Xanthomonas in brassicas/ leeks								

Combinable Crop Sector Workshop - Key Challenges & Priorities for Research

Crop Husbandry		Genetics		Environment & Social		Farming Systems		Engineering & IT	
***********	Closing the yield gap - understanding why	*********	N-fixing cereals	******	Overiding need for science/ evidence base regulation	*****	Improved economics of pulses	********	Variable rate fert & manure application
*****	Improved blackgrass control	****	GM traits for consumer benefits	******	Reducing N-use	****	Direct drilling in a maritime climate	****	In-crop testing of nitrogen/ protein content
****	Micro-nutrients & trace element nutrition	***	Genetic disease resistance	*****	Need for tramsparent & independent consistent research messaging	****	Benchmarking to integrate technical decisions wth economics & sustainability	***	Smart GPS pesticide application
***	Soil-borne diseases and rotational effects (take all & club root)	***	Pest-repellent traits (slugs, pigeons, aphids etc)	****	Loss of chemistry	***	Science skill base & career retention	**	Soil nutrient mapping
***	Mycotoxin management	**	Drought tolerance & abiotic stress resistance	****	Efficacy of sterile strips to prevent weed ingress	***	New (to UK) crops for climate change adaptation	**	Remote sensing (pests, disease, nutrients)
**	Disease management and implications for development of resistance	**	Protein genetics	***	Soil biology & soil structure	**	Resource use efficiency	**	Low/ zero-tillage systems
	Integrated weed control programmes	**	Improved rooting structure	***	Reducing water requirement - soil moisture holding capacitu	**	Better info on rotations	*	Sensors for farmer measurement of crop stands
	Inefficiency of nutrient use in OSR (root structure)	**	Maximising energy production (maize)	***	Landscape scale planning	**	New break crops for UK	*	Monitoring crop quality in store
		*	Improved multi-gene disease resistance	***	Sustainable intensification of environmental management	**	Regional impacts	*	Integrated decision analysis (IT)
		*	Natural standing power (no pgrs)	***	Standardised carbon footprinting	*	Nutrient cycling		Guidance systems
		*	Increased straw yields for livestock sector	**	Extreme weather impacts (drought & lodging)	*	Better integration of livestock & arable systems		Controlled traffic farming
		*	Post-emergence weed control	**	Slug resistance	*	Short growing season crops		Nanotechnology
		*	Phenotype expression under field conditions	*	Plant microbe interactions	*	Basic crop ecology & interactions		Compatability of IT systems
			Nutritional value of crops	*	Control of eutrophic algal blooms		Farm platform for arable farming		Variable seed rates
			Take-all & second wheat syndrome	*	Impact of climate change		Land sparing vs land sharing		Mobile soil-type mapping
			Improved milling qualities	*	Better evaluation of stewardship options on achieving desired outcomes (ELS/ HLS)		Cover & companion crops		Decision support systems
			Frost resistance	*	Use of selective herbicides in hedge bottoms				Fully automatic drying & storage systems
			Increased folic acid content (cereals)	*	Impact of carbon footprint on establishment/ management decision-making				Inter-row band spraying
			Understanding genetics of plant physiology/ biochemistry	*	Better understanding of trade-offs between production & environment				Whole-farm predictive modelling
			Genomic selection & molecular markers		KE? KT & barriers to uptake				Sensor development
			GM research in wheat pulses & soya for increased yields and RUE		Ecology of pests & disease and most effective points in rotation to control them				Automation of cultivation depth/ intensity to produce desired seedbed
					Over-reliance on single indicators for environment (farmland bird index)				Precision application of dusty materials
					N-fixation				
					Better understanding of causes of environmental interactions/ issues				
					Precision application/ CTF for environmental benefits				
					Anaerobic digestion				
					Implication of cultivations/ establishment methods for diffuse pollution and soil stability				
					Decrease reliance on non-renewable GHG-emitting resources				
					Improved use of water				
					Understanding of diffuse water pollution (protection of AIs)				
					Better info re growing grass margin/ pollen mixes				
					Dual-purpose food & fuel crops				

Summary of outputs from cross-sector R&D road-mapping workshop, 30th July 2012 – Stoneleigh

In attendance: David Alvis, Calum Murray – TSB, Ian Crute – AHDB, Andrea Graham – NFU, Jim Godfrey, Chris Pollock, David Gardner – RASE (afternoon session), Prof Charles Godfray – Oxford University/ Foresight, Tina Barsby – NIAB, Mike Bushell – Syngenta, Dave Hughes – Syngenta, Chris Tapsell – KWS/ BSPB, Richard Heathcote – Heineken, Ian Matts – YARA, Helen Browning – Soil Association, Tom MacMillan – Soil Association, Robert Merrall – IAgrE, Prof Dick Godwin – Cranfield Uni/ HAUC, Salvador Potter – PGRO, Angela Booth – ABAgri, Peter Mills – HAUC/ HTF, Duncan Sinclair – Waitrose

Summary of responses to key questions

Q1. PESTLE analysis: what are the key drivers that will have a significant impact on food production and the environment in the UK over the next 20 years?

Political:	**Economic:**
Globalisation of agri-food industry – loss of UK control	Rising food prices
Climate change policy	Changing diet – demand for animal protein
CAP reform	Global trade in commodities/ WTO
Food labeling	Supply chain resilience (UK and global)
Food prices and volatility (resilience and efficiency)	Oil price
Public sector investment	Analysis/ valuing diverse outputs from land
Future role of global commodity trading - WTO	Skills and education
Land use trade-offs	Reduction in public sector spending
Potential for global unrest	Duplication of R&D spend within Europe
Mass migration	Horizon 2020
Health and food safety policy	Increased competition in global markets
G8 agenda	Land ownership
Existing R&D structures	
EU Innovation Union (Horizon 2020)	

Social:	**Technological:**
CAP reform	Energy generation and use efficiency
Land use trade-offs	EU Innovation Union/ Horizon 2020
Consumer expectations (quality/ quantity)	Rise of national/ corporate technological 'super-powers'
Currency volatility and political/ social instability	IT, social media and communications technology
Long-term food price inflation	Remote sensing technologies
Food security – UK and global	Robotics
Health – food safety and diet	'Omics technologies – bioscience and bioinformatics
Population migration	Water management
Skills and education	Game changers – 'unknown unknowns'
Ageing population	Re-evaluation and access constraints
Image and reputation of food industry	GMOs and other contentious technologies
Awareness and acceptability of new technologies (GMOs, cloning etc)	Impact of aquaculture
ICT and social media	Sliding real terms investment in technology development
Nimbyism	
Rural infrastructure	
Consumer ethics	
Producer motivation	

Legal:	**Environmental:**
CAP reform	Land use trade-offs
Food safety legislation	Climate change
Anti-trust law	Sustainability issues and metrics
Intellectual property protection	Water and soil management
Trade deals/ WTO	Resource use efficiency
Regulatory environment and compliance	Benefits/ valuing non-agricultural outputs of land
Tax and capital allowances	Waste management
Planning law agricultural constraints and potential loss of productive land	Biodiversity and ecosystem services
Animal welfare regulation	Flood control and risk management
	Planning
	Emerging biotic pressures

Q2. What generic areas of research will have the most positive impact on the sustainable intensification of agriculture in the next 20 years?

Precision/ smart engineering *************

Soil biology, rhizosphere and water interactions **********

System-level research ************

(Relevant and objective) sustainability metrics *********

Genetics and marker-assisted selection/ 'omics' and understanding 'omic' information******

Social science – translation and communication *****

Nutrient use efficiency – nitrogen ***** and phosphorus **

Protein supply ***

Research motivation, R&D resilience and flexibility ***

Targeted KE/ KT for differing needs ***

New pest management techniques ** (incl. weed control)

GHGs and soil (N_2O)- and rumen (CH_4)-derived GHG mitigation *

Bio-informatics

Non-pathogenic disease/ metabolic disorders in livestock

Economics (drivers and impacts of commodity speculation)

Chemical engineering

Application of research from the ESRC and NERC

Synthetic biology

Photosynthetic efficiency

Commodity price dynamics and emergence of alternative oil/ protein sources (algae)

Artificial meat

Q3. What key challenges/ research needs were not highlighted/ identified by sector workshops?

Systems-level solutions – macro level *******

New/ emerging crops (grain maize, soya, alfalfa)******

Consumer psychology/ behaviour and trust *****

Impact assessment of R&D/ technology by stakeholders (incl. evidence) **

Quality of private sector research (capability) and open access – using private sector R&D for wider business benefit **

Application of genomics **

Optimising N use*

Modelling efficiency re GHGs*

Social science*

Greater industrial/ academic collaboration *

Structural issues in R&D capability (soil, weeds etc)*

Cell-level systems biology

Decision support tools

(Bio-) chemical feedstocks for industrial/ non-food use

Algae/ fungi as a source of feed/ protein/ energy

Q4. Given that current systems of agricultural production in the UK are driven largely by historical factors, what changes/ alternative farming systems should be investigated or researched to deliver sustainable productivity growth and provision of environmental goods in the future?

New paradigms in precision agriculture

Remote monitoring, control and application technologies

Protecting soils – controlled traffic farming

Protecting the environment – better targeting and timeliness of inputs

Environmental and economic benefit: defined – increased resource use efficiency/ yield/ reduced cost of compliance with regulations

Analysis, understanding and integration of yield mapping and soil/ crop monitoring data

Decision support tools

Outreach and training – KE/ KT requirement

Compatibility issues need to be resolved

Market pull – 'glorified red tractor'

Infrastructure investment

System design according to topography and soil type/ cropping etc.

Application of genomics in livestock

Move away from concept of 'breeds' particularly in dairy, beef and sheep

- Closer to pig and poultry sectors – system-focused hybrids – functional traits
- Redesign of the animal to suit the system of production
- Understanding and measuring commercially desirable traits
- Development/ identification of key trait markers across breeds
- Phenotyping and data collection. The challenge of collecting quality, standardised data across the supply chain.

Plant/ animal/ rumen metagenomics – optimising production systems

Recognise challenges and learn from past mistakes (dairy sector historical +++ selection for milk yield alone, deteriorating robustness, balanced breeding)

Producer inertia/ motivation/ power of breed societies

Consumer acceptance – perceived value of breeds/ differentiation

The precision ruminant.

Minimising biotic losses – crops

New chemistry

New biology

Integrated pest management

Mixed seed/ variety cropping

Paradigm change – 'learn to love pathogens'

- Work with nature

Primary biomass production; how to optimise

Pest and disease management with 'empty toolbox'

- Multi-factorial approach (ICM)

Core husbandry concepts (eg rotation): no magic bullet

Paradigm change – integrated mixed farming – co-location of specialist enterprises

- Mixed farming at regional/ area level rather than individual farm level
- Stop looking at the farm as the basic unit of measurement
- Efficient nutrient recycling – minimising losses
- Optimising value from co-products
- 'Circular agricultural economy' – identifying risks and opportunities

Wider cropping rotations – move away from reliance on wheat and OSR

- Breeding for multi-purpose crops
- How to achieve durable disease resistance

Exploration of potential upside of climate change – opportunity to grow more high-value crops

Transformation of production systems.

Soils and soil management

Soil biology, rhizosphere and water/ nutrient interactions

Better understanding of soil pathogens and life cycles/ interactions with soil biota/ crops

- Soil-borne disease pressures increasing
- No current solutions
- Requirement for national soil audit re soil health
- Public funding issue – value must be recognised
- Link outcomes to yield map data to identify potential causal links.

Valuing ecosystem services and developing land use systems to optimise delivery where appropriate

Tropical cropping systems/ wild harvest – what can be learned?

Vertical farming systems – opportunities in light of climate change

Prudent nutrient recycling

Dual cropping/ mixed farming systems (silvo-pastoral production)

Paradigm change; monitor ecosystem service output (how to measure/ value)

Re-definition of mixed land use

Rewarding ecosystem service eg agro-forestry

Logistical problems of low volume production

Unit of accountancy for ecosystem services (catchment NOT farm).

Endemic and emerging disease management and eradication in livestock

Identified as key challenge/ R&D priority theme in all animal sector workshops

Major cause of reduced productivity and source of waste/ GHGs/ welfare issues

Economic, environmental, welfare and resource use efficiency gains achievable: 'quadruple win' with few if any obvious trade-offs

Does industry's failure to adequately address this issue necessitate public sector intervention, given strategic importance of potential outcome?

Multivariate problem requires strategic and multi-factorial approach, including farm level, regional and national elements, to prevention, management and control of disease:

- Understanding causal links – genetic, nutritional, environmental, management, pathogen
- Identification and use of reliable health trait markers
- Balanced breeding goals for healthier/ robust livestock
- Influence of stress and system design/ animal environment on immune system
- Optimised management of herd health and biosecurity at farm, regional and national level.

Development of monitoring and diagnostic technologies

Development of persistent and effective vaccines

Anti-microbial resistance, and stratified therapy for optimised control strategies

Health economics – understanding the true cost of sub-clinical, chronic and acute infection in a range of key diseases/ disorders

Effective KT/ KE mechanisms to raise awareness and drive widespread adoption of best practice/ new technology to improve herd health.

Q5. What other factors (positive and negative) will have a significant effect on agricultural production between now and 2030, and what role does R&D play in ensuring those impacts are optimised/ mitigated against?

Positive factors:

1. Consolidation/ collaboration of agricultural R&D with other strategic imperatives

Eg energy and AD

- Integrated management of complexity
- Structured approach to R&D programming.

2. Climate change opportunity

Embrace systems biology

- Increase diversity of genetic pool in agricultural production
- Increase resilience (plants and livestock).

3. Rising demand for food

Drive for efficiency gains

- GHG/ U energy balance

Political rhetoric – action

- Increasing recognition of importance of agriculture/ food production (BIS and Defra)

Impact of dietary change in developing world (meat consumption ++).

Risk factors:

1. Consolidation and increased unit size (without collaboration)

- Need for economic and bioscience research
- Need for key skills to manage complexity and integration of systems.

2. Absence of bespoke agri-business training

3. New landowners: more contract farming

Short-term planning horizon

Fragmentation of holdings

Lifestyle landowners/ nimbyism vs productivity

Potentially less commitment to driving productivity gains.

4. Climate change

No national adaptation plan

Conventional breeding techniques inadequate due to changing environmental conditions

Expected +ve CO_2 response may not occur due to other limiting factors

- Robust models required for plants and animals.

5. Carbon accounting

UK has irreducible minimum agricultural carbon footprint

- What is it?

6. Antimicrobial resistance

Concerns over resistance in humans limiting/ reducing availability of veterinary drugs

Disparity of regulatory system between major production areas (EU vs US)

Lack of R&D in animal health products

7. EU regulatory system

Restricting uptake of new technology (GMOs, cloning) and potential loss of existing technology (assessment by hazard rather than risk)

8. Dietary change in developed world (reduced meat consumption)

Appendix 4. Examples of successful integrated R&D programmes in the agricultural sector.

1. The Australian model for applied agricultural research: rural development corporations

Rural development corporations commission agricultural research on a competitive basis from both public and private providers, using funds from production levies that are matched (up to a ceiling of 0.5% of the value of production) by federal funds. There are currently 15 RDCs, each based around single rural industries, although there is considerable variation in their detailed terms of reference. In 2007 total RDC expenditure on traditional agricultural production research was ca A$ 0.5bn (some 60% of total public expenditure on agricultural R&D, and approximately 50% of the expenditure on production agriculture). This model is felt to have several advantages:

- Strong linkages to producers help to ensure value for money
- These linkages also promote rapid uptake by producers
- The relatively large sums of money involved are used to promote integrated approaches to R&D, particularly in areas where there are other funders
- RDCs are seen as a valuable intellectual resource in terms of expertise in rural research management that feeds through into policy issues.

An economic analysis of value for money from R&D investment suggests that domestic research (50% of which comes via the RDCs) is responsible for about 60% of recent productivity increases in broad acre agriculture. The author suggests that, without this research, the real value of output would have contracted by around 50% between 1953 and 2008.

Recent reviews have identified challenges in following this model, although there is considerable debate over the need for and nature of reform. The current intention is to adapt rather than replace it. The incentive for increased direct industry investment in R&D may be too little, and there is an argument about reducing the ceiling for matched federal funds. Small rural industries and overarching rural issues are not dealt with effectively through this system, and there is a risk that the terms of reference for some RDCs can limit their independence of action.

The key lesson for the UK remains, however, the effectiveness of RDCs (a) in linking industry and Government funding to deliver R&D that directly benefits industry, (b) in mobilising long-term private R&D investment in industries dominated by many small businesses, where individual private investment would be unlikely or ineffective, and (c) in providing an industry-aware focus for setting and delivering against strategy.

1. Mullen, J (2010). Trends in Investment in Agricultural R&D in Australia and its Potential Contribution to Productivity. Australasian Agribusiness Review - Vol.18 - 2010, Paper 2, ISSN 1442-6951.

http://www.ruralrdc.com.au

2. The Consortium for Plant Biotechnology Research, St Simons Island, Georgia, USA.

The CPBR is a non-profit NGO whose aim is to speed-up the transfer of plant biotechnologies from the research laboratory to the marketplace, expanding economic opportunities through university research and global networking. The consortium supports biotechnology research that has practical applications, it advances technological innovations based on new understandings and uses of plants and other organisms, it provides multidisciplinary training and research opportunities for a new generation of scientists and engineers, and it connects industry needs with university and industry suppliers.

The CPBR's generic (anonymous) list of company members' research needs is updated annually by the companies involved. The list becomes part of the CPBR Request for Pre-proposals, which is sent to member university scientists and administrators. It invites the scientists to respond to the company members' research needs with short descriptions of proposed research projects. Full proposals for funding are submitted to the centre by a variety of academic providers. The selection process includes industrial evaluation of research concepts to insure industrial relevance and peer review to insure scientific excellence, and funds requested from CPBR must be matched at least 1:1 by funds from companies and other non-federal sources, such as universities and foundations. Each proposal must have part of the required 1:1 matching come from a for-profit company as cash matching. Since 1989, over $120m has been directed to projects, with non-federal funds accounting for almost $70m.

In terms of outputs, Consortium-funded projects delivered over 200 patents, over 250 licenses and five start-up companies, but perhaps more importantly the success rate per unit of federal funding was significantly higher for patents, licences and peer-reviewed publications than the average for American universities.

The key lesson for the UK is in the advantages of linking more closely the aims and objectives of industrial funding in plant biotechnology with the programme of research funded by central government. Given the pressures on funding overall and the impetus for work on alternative land use, the TSB and the levy payers also have a key role to play in this area.

http://www.cpbr.org

3. Canadian Agri-Science Clusters

Total funding of $68.5m has been approved under the Canadian Agri-Science Clusters initiative of the Growing Canadian Agri-Innovations Programme. This funding is being allocated to 10 science clusters which are organised along commodity lines, as follows: beef cattle, dairy, swine/ pork, poultry, canola/ flax, pulse, wheat breeding, edible horticulture, ornamental horticulture, and organic agriculture.

The initiative provides financial funding contributions for recipients to carry out research projects with universities and other research and development organisations. Funding may also cover non-pay costs associated with research to be performed at Agriculture and Agri-Food Canada research facilities. The lead organisation is accountable for the execution of the project and all associated reporting of expenditures and results.

Recipients must be not-for-profit agricultural corporations. These tend to occupy a niche similar to that of the UK levy bodies. Recipients must contribute financially toward the cost of research undertaken; industry contributions range from 15 per cent of the project cost to as high as 30 per cent.

This programme provides a potential model for individual levy bodies/ producer groups to engage more effectively with basic and strategic research in areas that lie outside the generic research priorities identified in the body of this report. It does, however, rely heavily on earmarked federal funding.

http://www4.agr.gc.ca

4. The UK Crop Improvement Research Club (CIRC)

CIRC is a £7.06m, five-year partnership between the BBSRC, the Scottish Government and a consortium of leading companies, aimed at supporting innovative and excellent research to underpin the development of improved crop varieties. There is an urgent need to develop crop varieties with greater yield potential, and the ability to deliver this sustainably with reduced inputs, and without detrimental effects on the local ecosystem. Equally, new crop varieties are required that reliably and consistently produce high quality products that are safe, nutritious and meet end-user requirements.

The challenge for industry will be to achieve high-yielding, high-quality varieties that perform well in a commercial context against a background of greater environmental instability, particularly as a result of climate change.

The CIRC themes are:

- To support research leading to improved crop productivity.

Sustainable improvements in crop productivity are important for increasing the volume of food the UK can produce, for limiting the land needed to produce this food and for improving the efficiency with which resources are used in crop production.

- To support research leading to improved crop quality.

Improving quality can help to improve the processing, safety and nutritional value of crop products, whilst also improving resource use efficiency. By understanding quality traits better there will also be scope for generating greater consistency in quality against a background of variation in growing conditions.

CIRC will support research on oilseed rape, barley and wheat and their uses in food production for humans and animals.

14 companies have agreed to join CIRC to date. CIRC will support research projects from a joint fund totalling £7.06m, with £6m coming from the BBSRC, £0.56m from industry and £0.5m from the Scottish Government.

This is a good UK example of an integrated programme structured around medium- and long-term producer needs that seeks to integrate basic and strategic research and link this to a clear delivery pathway. It is one of five research and technology clubs involving the BBSRC.

http://www.bbsrc.ac.uk/business/collaborative-research/industry-clubs/crop/crop-index.aspx

Appendix 5.
Acronyms used in this report

AIC	Agricultural Industries Confederation
AHDB	Agriculture and Horticulture Development Board
BBRO	British Beet Research Organisation
BBSRC	Biotechnology and Biological Sciences Research Council
BIS	Department for Business, Innovation and Skills
CFG	Commercial Farmers Group
CPD	Continuous Professional Development
CTF	Controlled Traffic Farming
Defra	Department for Environment, Food and Rural Affairs
DfID	Department for International Development
EBLEX	English Beef and Lamb Executive
EU	European Union
FEI	Further Education Institutions
GHG	Greenhouse Gases
GPS	Global Positioning System
HCC	Hybu Cig Cymru (Welsh Meat)
HDC	Horticulture Development Council
HEI	Higher Education Institutions
HGCA	Home Grown Cereals Authority
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology for Development
IAgrE	Institute of Agricultural Engineers
KT	Knowledge Transfer
KTN	Knowledge Transfer Network
MAFF	Ministry of Agriculture, Fisheries and Food
NERC	Natural Environment Research Council
NFU	National Farmers' Union
PCL	Potato Council
PGRO	Processors and Growers Research Organisation
RASE	Royal Agricultural Society of England
R&D	Research & Development
RCs	Research Councils
RCUK	Research Councils United Kingdom
RURAL	Responsible Use of Resources for Agriculture and Land
SEERAD	Scottish Executive Environment Rural Affairs Department
TSB	Technology Strategy Board

For more information please contact:

AHDB – Ian Crute
Chief Scientist
ian.crute@ahdb.org.uk

NFU – Andrea Graham
Chief Land Management Adviser
andrea.graham@nfu.org.uk

AIC – Paul Rooke
Head of Policy, External Affairs
Cereals & Oilseeds
paul.rooke@agindustries.org.uk

RASE – David Gardner
Chief Executive
davidg@rase.org.uk

NFU Scotland – Nigel Miller
President
nigel.miller@nfus.org.uk

Technology Strategy Board – Calum Murray
Lead Technologist, Sustainable Agriculture
& Food Innovation Platform
calum.murray@tsb.gov.uk

AHDB Agriculture & Horticulture DEVELOPMENT BOARD

aic agricultural industries confederation

ROYAL AGRICULTURAL SOCIETY of ENGLAND

NFU

NFU Scotland

Technology Strategy Board
Driving Innovation

www.feedingthefuture.info

May 2013 T13/49